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TECHNICAL MEMORANDUM

A Comparison of RESRAD-Build with the Online EPA BPRG Calculator Tool for the Armstrong Building at the Welsbach/GGM Superfund Site

US Army Corps of Engineers
Kansas City District
9 June 2011

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A Comparison of RESRAD-Build with the Online EPA BPRG Calculator Tool for the Armstrong Building at the Welsbach/GGM Superfund Site
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EXCUTIVE SUMMARY

1. The US Army Corps of Engineers (USACE) prepared this Technical Memorandum (TM) in support of US Environmental Protection Agency (EPA) Region 2 and the Welsbach/GGM Superfund Project. Based on discussions herein USACE has determined that the Department of Energy (DOE) RESidual RADioactivity in BUILDings RESRAD-Build version 3.5 (DOE 2009) (developed by the Argonne National Laboratory) is an acceptable model to develop site specific criteria at the Armstrong Building of the Welsbach/GGM Superfund Project.

2. **Purpose:** The Purpose of this TM is to provide a comparison of RESRAD-Build (RESBLD) and the current online version of the EPA Preliminary Remediation Goals for Radionuclides in Buildings (BPRG) calculator (EPA 2009) (developed by the Oak Ridge National Laboratory). This TM also provides an estimate of reasonable Derived Concentration Guideline Levels (DCGL) potentially to be applied at the Armstrong Building of the Welsbach/GGM Superfund Project.

3. **Conclusions**

3.1 The RESRAD-Build Model and BPRG calculator compare favorably. The ability for RESRAD-BLD to better model future use scenarios and to be more site specific is an advantage to the Armstrong Building project team due to the amount of site specific data available from the Remedial Investigation (RI) and the recent supplemental RI.

3.2 The online BPRG calculator serves as a useful tool for a first estimate of screening levels at the Armstrong Building. The incorporation of site specific data into the BPRG calculator and then into RESRAD-Build has facilitated the evolution of initial generalized BPRG derived values into more accurate and site specific DCGLs ranges.

3.3 A better understanding of the BPRG calculator and how it handles complex decay chain calculation for future use scenarios is required before USACE can recommend use of the BPRG calculator to develop DCGLs for the Th-232 decay chain.

4. Recommendations

4.1 **Use** of the RESRAD-BLD code to develop DCGLs for the Armstrong Building at the Welsbach/GGM Superfund site is recommended due to the amount of available site specific data and the flexibility of the model.

4.2 Developed DCGLS should be well within the ranges of DCGLs presented in Table 5.

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3**. Discussions**

3.1 Background

3.1.1 As part of the Baseline Risk Assessment (BRA) at the Armstrong Building, the computer code RESBLD was used to model interior contamination at the Armstrong Building to determine site specific risk levels and further in the draft Feasibility Study (FS) to develop site specific Derived Concentration Guideline Levels (DCGLs) for each contaminant of concern (COC). To further evaluate the appropriateness of derived DCGLs, the output of the site specific RESBLD model was compared to results from EPAs (BPRG) model via the online calculator tool.

3.1.2 RESRAD-Build version 3.5

USACE has used the RESRAD and RESRAD-Build computer codes at numerous Department of Defense (DOD), DOE, EPA, and Nuclear Regulatory Commission (NRC) sites and projects.

According to the RESBLD User's guide –

> *"….. the manual and code have been used widely by the U.S. Department of Energy and its contractors, the U.S. Nuclear Regulatory Commission, and many other government agencies and institutions."*

> *"The RESRAD-BUILD computer code is a pathway analysis model designed to evaluate the potential radiological dose incurred by an individual who works or lives in a building contaminated with radioactive material. The transport of radioactive material within the building from one compartment to another is calculated with an indoor air quality model. The air quality*

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model considers the transport of radioactive dust particulates and radon progeny due to air exchange, deposition and resuspension, and radioactive decay and ingrowth. A single run of the RESRAD-BUILD code can model a building with up to three compartments, four source geometries (point, line, area, and volume), 10 distinct source locations, and 10 receptor locations. The volume source can be composed of up to five layers of different materials, with each layer being homogeneous and isotropic. A shielding material can be specified between each source-receptor pair for external gamma dose calculations. The user can select shielding material from eight different material types. Seven exposure pathways are considered in the RESRAD-BUILD code: (1) external exposure directly from the source, (2) external exposure to materials deposited on the floor, (3) external exposure due to air submersion, (4) inhalation of airborne radioactive particulates, (5) inhalation of aerosol indoor radon progeny and tritiated water vapor, (6) inadvertent ingestion of radioactive material directly from the source, and (7) ingestion of materials deposited on the surfaces of the building compartments. Various exposure scenarios may be modeled with the RESRAD-BUILD code. These include, but are not limited to, office worker, renovation worker, decontamination worker, building visitor, and residency scenarios. Both deterministic and probabilistic dose analyses can be performed with RESRADBUILD, and the results can be shown in both text and graphic reports."

3.1.3 EPA BPRG Calculator

USACE has used the EPA BPRG calculator at a few sites and projects; however, to date our experience with it is less than that with RESRAD-Build.

According to the BPRG User's guide –

"This guidance document sets forth recommended approaches based upon the current available and relevant science with respect to risk assessment for response actions at CERCLA sites. This document does not establish binding rules. Alternative approaches for risk assessment may be found to be more appropriate at specific sites (e.g., where site circumstances do not match the underlying assumptions, conditions and models of the recommended guidance). The use of this recommended guidance or of alternate approaches in the consideration or selection of remedial or removal actions on CERCLA sites should be reflected in the Administrative Records for such sites."

"PRGs are risk-based, conservative screening values that can be used to identify areas and contaminants of potential concern (COPCs), and that either do or do not warrant further investigation. PRGs typically are tools for evaluating and cleaning up contaminated sites. They are not de facto *cleanup standards and should not be applied as such; however, they may be helpful in providing long-term targets to use during the analysis of remedial alternatives. In general, generic PRGs are used before site-specific risk assessments as a screening tool. After the baseline risk assessment, PRGs are typically refined to incorporate site-specific knowledge and conditions.*

This calculator is based on Risk Assessment Guidance for Superfund: Volume I, Human Health Evaluation Manual (Part B, Development of Risk-based Preliminary Remediation Goals) (RAGS Part B). RAGS Part B provides guidance on using EPA toxicity values and exposure information to calculate risk-based recommended BPRGs. Recommended for initial use at the scoping phase of a project using readily available information, risk-based recommended BPRGs generally are modified based on site-specific data gathered during the RI/FS study."

3.2 Comparisons

3.2.1 General Comparisons

The two models are based on similar guidance and information. In fact the BPRG manual states, "*Calculation of the recommended BPRGs are based on the risk assessment work (EPA 2003) for chemicals and RESRAD BUILD (Developed for the U.S. Department of Energy by Argonne National Laboratory) and the default inputs are based on Superfund parameters.*" Accordingly if the two models were used to model the exact same exposure scenario it is expected that the ultimate results would be similar.

A significant difference between the two models is that RESBLD can provide dose and risk modeling given a source exposure scenario where BPRG is designed to output a screening value given a target risk. By design BPRG does not consider radiation dose. Thus, the two models approach the same scenario differently. Stated differently, RESBLD with model input, including COC source concentration, provides an estimate of dose and risk while BPRG with model inputs, including target risk value, provides an acceptable COC concentration.

Another difference between the models is the application to current and future scenarios. BPRG is very effective at determining screening values for current occupancy scenarios (resident and worker) in three primary exposure paths/media (air, dusts, external). BPRG provides screening values for each separately while RESBLD combines the exposure from each to one value as well as reports path/media specific values that can be used to determine specific screening values.

For future use scenario criteria development the EPA BPRG approach assumes that significant source removable is unlikely and that portion that may become removable is subject to removal by cleaning (vacuuming, dusting, etc.) thus insignificant. Accordingly, for future use criteria, the BPRG external exposure model should be used. The BPRG calculator may not be suitable for determining DCGLS if the future removable fraction is likely to exceed that removed by cleaning. The amount of future removable contamination and the level and frequency of cleaning conducted in a future home or office adds significant uncertainty to the use of either model. RESRAD-Build is capable of modeling these factors in future use scenarios while BPRG is not.

Another difference between the models is flexibility and data requirements. RESBLD allows for many more site specific inputs than BPRG, thus it is a more flexible model. To take full advantage of this flexibility, significantly more site specific data is required. Alternatively, the BPRG calculator is designed to standardize the evaluation and cleanup of radioactively contaminated buildings for which risk is being assessed. BPRG requires zero to little site specific information. Examples of model input differences are included in Table 1.

Table 1. General Comparison of Models

	RESRAD-BLD	BPRG	Note
# Exposure Scenarios	5+ (any)	2 (resident, worker)	BPRG notes that other scenarios could be investigated by altering inputs
# Exposure Pathways	7	6	RESRAD BLD adds radon and tritiated water
Room size	Any	Choice of 5 sizes	RESRAD BLD can be set to match BPRG.
# Receptors	Up to 10	1	RESRAD BLD can be set to match BPRG.
# Receptor locations	Up to 10	4 choices	BPRG does have an average position
# of Sources	Up to 10	1	BPRG assumes all room surfaces contaminated
# of rooms	Up to 3	1	
Source inputs	Site specific (flexibility)	Standard, no input	BPRG considers hard and soft surfaces
Outputs	Dose or risk	Activity	Can use either to calculate the other

3.2.2 Specific Comparisons

While both models provide output for Ambient air it should be noted that the BPRG Ambient Air calculator was not evaluated as it provides a PRG value only for volumetric air concentrations and does not calculate a surface PRG. The RESBLD model evaluates the air concentrations inherently.

The BPRG model uses a direct ingestion settled dusts model to account for the direct ingestion of radionuclides, which is not the scenario at the Armstrong building. It is known that much of the contamination present is fixed contamination rather than contamination present as ingestible dust particulates. For the purpose of RESBLD modeling, 10% of the contamination was assumed to be removable with a life time of 100 years and modeled as indirect ingestion of dust. As such, the BPRG dust model will likely over estimate risk from internal deposition of surface contamination by determining a value for contamination based on an assumption that 100% of the contamination is available for direct ingestion.

Conversely, the BPRG external model derives PRG values based solely on external exposure from radionuclide contamination without taking into consideration internal deposition from inhalation or ingestion and as such may under estimate the dose from alpha and beta emitting radionuclides such as those present in the Armstrong building.

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Because the BPRG models will tend to over-estimate dose in the dust settling model and may under estimate dose in the external model it is a useful tool to develop initial screening criteria and to provide some idea of the upper and lower ranges of DCGLs, which can be compared to DCGLs derived from RESRAD-Build.

To compare the two models the parameters for RESBLD were adjusted to reflect the inputs of the BPRG calculator and the site as close as possible. A 50' x 50' x 10' room was modeled with a receptor located in the center of the room and breathing rates and dissipation rates were matched between the two models. Note that this is larger than the 100 square meter of floor area recommended in the Multi-Agency Radiation Survey and Site Investigation Manual (EPA 2000).

Tables 2 and 3 show comparisons of the RESBLD residential DCGL values compared to default and site specific PRGs derived from the BPRG calculator. In order to match the site specifics, the BPRG calculator model included adjustments for exposure time, room size, and dissipation rate, which made a small difference in DCGL values between the default and site specific case.

Table 2. Residential Default Case ($1x10^{-4}$ risk) ($dpm/100cm^2$)

Radionuclide	BPRG Settled Dust	BPRG 3-D Direct External Exposure	RESRAD-Build
Thorium 232	71	924,000	
Radium 228+D	26	879	
Thorium 228	617	1,980,000	
Radium 224+D	1,230,000	977,000	
Total thorium	**18**	**877**	**307**
Radium 226+D	**22**	**355**	**884**

Table 3. Residential Site Specific Case ($1x10^{-4}$ risk) ($dpm/100cm^2$)

Radionuclide	BPRG Settled Dust	BPRG 3-D Direct External Exposure	RESRAD-Build
Thorium 232	90	1,784,880	
Radium 228+D	33	1,334	
Thorium 228	781	3,596,400	
Radium 224+D	1,560,660	1,374,180	
Total thorium	**23**	**1,331**	**307**
Radium 226+D	**28**	**526**	**884**

From the comparison we can see that for thorium contamination the RESBLD derived DCGL of 307 dpm/100 cm^2 falls between the two site specific model values of 23 dpm/100 cm^2 and 1,331 dpm/100 cm^2. This suggests that the models are in good agreement based on the fact that analysis of the RESBLD generated risk assessment shows that the risk to a receptor comes approximately 50% from external radiation and 50% inhalation.

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A comparison of the radium 226+D DCGL value of 884 dpm/100 cm^2 derived from RESBLD to the external exposure PRG of 526 dpm/100 cm^2 from the site specific BPRG model also shows that the two models are in agreement when model uncertainty is considered. It was noted during the evaluation that while both the BPRG model and RESBLD cite FGR 13 and HEAST 2001 as the sources of their slope conversion factors for risk assessment, the User's Guide for the Online BPRG Calculator notes that the ground plane slope factor used was *developed* specifically for the BPRG from values from FGR 13. As such it's likely that the two models handle risk coefficients slightly differently and can be expected to give slightly different values.

Additionally, the BPRG calculator models external exposure as a result of contamination present in an infinite plane. Though the model corrects for this using a surface factor this is another area where the models differ and could be expected to produce results that differ slightly.

Ultimately, both models arrive at similar values at the desired risk range. The fact that the BPRG derived PRGs and the RESBLD DCGLs compare well is not surprising, as much of the calculations and framework of the two models come from the same source. Again citing the online User's Manual for the BPRG calculator –

> *"Calculation of the recommended BPRGs are based on the risk assessment work EPA 2003 for chemicals and RESRAD BUILD (Developed for The U.S. Department of Energy by Argonne National Laboratory) and the default inputs are based on Superfund parameters."*

4. DCGL Discussions

4.1 The comparisons in paragraph 3 above were conducted to best compare the two models. The RESBLD model was changed slightly from that used in the BRA and FS to better match the BPRG model for comparison purposes. As such the DCGLs presented in Tables 1 and 2 will likely not match those in the final FS.

4.2 The comparison used a fixed $1x10^{-4}$ risk as the upper bound of the acceptable risk range. As discussed in EPA OSWER Directive 9200.4-18 (EPA 1997) the risk range is not a hard line and especially when meeting dose based ARARs exceeding $1x10^{-4}$ risk may be acceptable.

4.3 The OSWER 9200.4-18 (EPA 1997) also states that 15 mrem/yr roughly equates to 3.4×10^{-4} risk, and considers this acceptable.

4.4 The Welsbach/GGM Superfund Site is in New Jersey. New Jersey has a promulgated standard (NJAC 7:28-12, NJDEP 2000) for protection from residual radiation exposure of 15 mrem/yr. Accordingly, there is a potential that this standard may become an ARAR for the Armstrong Building Operable Unit.

4.5 Modifying the acceptable risk to $3x10^{-4}$ effectively would triple the DCGLs presented in Tables 2 and 3 above. Table 4 presents site specific DCGLs based on $3x10^{-4}$ risk.

4.6 Table 5 presents a range of acceptable DCGLs for the Armstrong Building given the different models and site specific inputs.

Table 4. Residential Site Specific Case (3x10^{-4} risk) (dpm/100cm^2)

Radionuclide	[1]Settled Dust	3-D Direct External Exposure	RESRAD-Build
Thorium 232	270	5,354,640	
Radium 228+D	99	4,002	
Thorium 228	2343	10,789,200	
Radium 224+D	4,681,980	4,122,540	
Total thorium	**69**	**3,993**	**921**
Radium 226+D	**84**	**1,578**	**2,652**

[1] Eliminated from consideration due to future use scenario limitations, see paragraph 3.2.1.

Table 5. DCGL Range (dpm/100cm^2)

Radionuclide	BPRG Range	RESBLD Range	Combined Range
Th-232 (chain)	1,331 – 3,993	307 - 921	307 – 3,993
Ra-226+D	526 - 1,578	884 – 2,652	526 – 2,652

5. Uncertainty

5.1 It should be noted that significant uncertainty is inherent in any modeling and most are not discussed here. Ultimately the BRA and the FS will address DCGL model uncertainty.

5.2 USACE compared the BPRG calculator external exposure model DCGL results for the Th-232 and Ra-226 decay chains versus hand calculations and calculating the decay chain DCGL by individual radionuclide versus using the +D radionuclide inputs.

5.2.1 Hand calculations verified the BPRG calculator worked as designed. In some instances, significant figures truncating or rounding add some level of uncertainty between hand calculations and the BPRG calculated and reported results. This difference is unlikely to be significant but should be understood when developing DCGLs.

5.2.2 In theory, using an individual decay chain radionuclide approach and a radionuclide+D approach should result in similar DCGLs. For the Ra-226 decay chain and the Th-232 decay chain significant differences in the resulting DCGLS were observed between the individual and +D approaches. This may be due to several factors which are not fully understood by USACE at this time. Significant uncertainty appears to exist in the use of BPRG calculator for future use scenarios and complex decay chain calculations especially the Th-232 decay chain.

6. Conclusions

6.1 The RESRAD-Build Model and BPRG calculator compare favorably. The ability for RESRAD-BLD to better model future use scenarios and to be more site specific is an advantage to the Armstrong Building project team due to the amount of site specific data available from the Remedial Investigation (RI) and the recent supplemental RI.

6.2 The online BPRG calculator serves as a useful tool for a first estimate of screening levels at the Armstrong building. The incorporation of site specific data into the BPRG calculator and then into RESRAD-Build has facilitated the evolution of initial generalized BPRG derived values into more accurate and site specific DCGLs ranges.

6.3. A better understanding of the BPRG calculator and how it handles complex decay chain calculation for future use scenarios is required before USACE can recommend use of the BPRG calculator to develop DCGLS for the Th-232 decay chain.

7. Recommendations

7.1 **Use** of the RESRAD-BLD code to develop DCGLs for the Armstrong Building at the Welsbach/GGM Superfund site is recommended due to the amount of available site specific data and the flexibility of the model.

7.2 Developed DCGLS should be within the ranges of DCGLs presented in Table 5.

8. References

DOE 2009 *RESRAD-Build User Manual*, Environmental Assessment Division, Argonne National Laboratory. Argonne, Illinois. ANL/EAD/03-1. June. Model Updated 2009.

EPA 2009 *Preliminary Remediation Goals for Radionuclides in Buildings* (BPRG) User's Guide Last updated on Tuesday, July 8th, 2008. Model update 2009.

EPA 2000 *Multi-Agency Radiation Survey and Site Investigation Manual* (MARSSIM), Revision 1. EPA, August 2000.

EPA 1997 OSWER 9200.4-18, *Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination*, EPA, OFFICE OF SOLID WASTE AND EMERGENCY RESPONSE, August 20, 1997.

NJDEP 2000 *New Jersey Administrative Code* (NJAC 7:28-12). Radiation Protection Programs, Subchapter 12, Remediation Standards for Radioactive Materials, August.

Attachment 1

Summary Tables from BPRG Calculator

Site-specific	
Resident Equation Inputs for Settled Dust	
Variable	**Value**
TR (target cancer risk) unitless	0.0001
t_r (time - resident) yr	30
F_{in} (fraction time spent indoors) unitless	0.875
k (dissipation rate constant) yr^{-1}	0.01
EF_r (exposure frequency) day/yr	365
F_{AM} (area and material factor) unitless	1
ET_r (exposure time) hr/day	24
$F_{OFF-SET}$ (off-set factor) unitless	1
F_i (fraction of time spent in compartment) unitless	1
$FTSS_h$ (fraction transferred surface to skin - hard surface) unitless	0.5
SE (saliva extraction factor) unitless	0.5
IFD_{r-adj} (age-adjusted dust ingestion rate - resident) cm^2/day	3870
ED_r (exposure duration - resident) yr	30
ED_{r-a} (exposure duration - resident adult) yr	24
ED_{r-c} (exposure duration - resident child) yr	6
$ET_{r-c,h}$ (exposure time - resident child hard surface) hr/day	6
$ET_{r-a,h}$ (exposure time - resident adult hard surface) hr/day	6
$ET_{r-c,s}$ (exposure time - resident child soft surface) hr/day	10
$ET_{r-a,s}$ (exposure time - resident adult soft surface) hr/day	10
FQ_a (frequency of hand to mouth - adult) event /hr	1
FQ_c (frequency of hand to mouth - child) event/hr	9.5
SA_{r-a} (surface area of fingers - resident adult) cm^2	45
Output generated 31MAY2011:13:51:09	

Site-specific				
Resident Building Preliminary Remediation Goals for Settled Dust				
Radionuclide	**Soil Ingestion Slope Factor (risk/pCi)**	**Ground Plane External Exposure Slope Factor (risk/yr per pCi/cm^2)**	**Lambda**	**BPRG (pCi/cm^2)**
Ra-224+D	-	1.30E-06	6.91E+01	7.03E+03
Ra-226+D	7.30E-10	1.54E-06	4.33E-04	1.24E-01
Ra-228+D	2.29E-09	2.16E-06	1.21E-01	1.49E-01
Th-228	2.89E-10	1.87E-09	3.62E-01	3.52E+00
Th-232	2.31E-10	3.20E-10	4.93E-11	4.05E-01
Output generated 31MAY2011:13:51:09				

Site-specific	
Resident Equation Inputs for 3-D Direct External Exposure	
Variable	**Value**
Room size & position	50 x 50 x 10 - Average
TR (target cancer risk) unitless	0.0001
F_i (fraction of time spent in compartment) unitless	0.875
$F_{OFF-SET}$ (off-set factor) unitless	1
ED_r (exposure duration - resident) yr	30
ET_r (exposure time - resident) hr/day	24
t_r (time - resident) yr	30
F_{in} (fraction time spent indoors) unitless	1
F_{am} (area and materials factor) unitless	1
EF_r (exposure frequency) day/yr	365
GSF (gamma shielding factor) unitless	1
Output generated 31MAY2011:13:51:09	

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Site-specific				
Resident Building Preliminary Remediation Goals for 3-D Direct External Exposure				
Radionuclide	**Ground Plane External Exposure Slope Factor (risk/yr per pCi/cm^2)**	**F_{SURF}**	**Lambda**	**Ground Plane BPRG (pCi/cm^2)**
Ra-224+D	1.30E-06	0.981	6.91E+01	6.19E+03
Ra-226+D	1.54E-06	1.05	4.33E-04	2.37E+00
Ra-228+D	2.16E-06	1.09	1.21E-01	6.01E+00
Th-228	1.87E-09	1.37	3.62E-01	1.62E+04
Th-232	3.20E-10	1.48	4.93E-11	8.04E+03
Output generated 31MAY2011:13:51:09				

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Attachment 2

Th-232 Decay Chain

Summary Tables from BPRG Calculator VS Hand Calculation

And

Individual DCGL vs +D Comparison

Model Inputs for Check of Individual Calcs

BPRG Calculator	50x50x10 room average receptor location
Variable	**Value**
Room size & position	50 x 50 x 10 - Average
TR (target cancer risk) unitless	1.00E-06
F_i (fraction of time spent in compartment) unitless	1
$F_{OFF\text{-}SET}$ (off-set factor) unitless	1
ED_r (exposure duration - resident) yr	30
ET_r (exposure time - resident) hr/day	24
t_r (time - resident) yr	30
F_{in} (fraction time spent indoors) unitless	0.875
F_{am} (area and materials factor) unitless	1
EF_r (exposure frequency) day/yr	350
GSF (gamma shielding factor) unitless	1

Ground Plane BPRG (pCi/cm^2)	Radionuclide	External Exposure Slope Factor (risk/yr per pCi/g)	Ground Plane External Exposure Slope Factor (risk/yr per pCi/cm^2)	External Exposure Slope Factor (1 cm) (risk/yr per pCi/g)	External Exposure Slope Factor (5 cm) (risk/yr per pCi/g)	External Exposure Slope Factor (15 cm) (risk/yr per pCi/g)	F_{SURF}	Lambda	Soil Volume BPRG (pCi/g)	Ground Plane BPRG (pCi/cm^2)	Soil Volume BPRG (1 cm) (pCi/g)
1.09E+03	Ac-228	4.53E-06	8.56E-07	5.48E-10	2.49E-06	3.92E-06	1.26	9.90E+02	2.07E+02	1.09E+03	1.71E+06
2.97E+04	Bi-212	8.88E-07	1.71E-07	1.06E-10	4.82E-07	7.64E-07	1.41	6.02E+03	5.73E+03	2.97E+04	4.80E+07
5.40E+03	Pb-212	5.09E-07	1.26E-07	7.95E-11	3.46E-07	4.89E-07	0.999	5.71E+02	1.34E+03	5.40E+03	8.56E+06
-	Po-212	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	7.17E+13	-	-	-
1.30E+13	Po-216	7.87E-11	1.52E-11	9.73E-15	4.40E-11	6.90E-11	0.88	1.46E+08	2.51E+12	1.30E+13	2.03E+16
9.77E+03	Ra-224	3.73E-08	8.58E-09	5.50E-12	2.46E-08	3.56E-08	0.983	6.91E+01	2.25E+03	9.77E+03	1.52E+07
6.46E+01	Ra-224+D	7.77E-06	1.30E-06	8.42E-10	3.90E-06	6.33E-06	0.981	6.91E+01	1.08E+01	6.46E+01	9.97E+04
-	Ra-228	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	1.21E-01	-	-	-
6.27E-02	Ra-228+D	1.23E-05	2.16E-06	1.39E-09	6.39E-06	1.03E-05	1.09	1.21E-01	1.10E-02	6.27E-02	9.74E+01
1.69E+02	Th-228	5.59E-09	1.87E-09	1.03E-12	4.17E-09	5.49E-09	1.37	3.62E-01	5.64E+01	1.69E+02	3.06E+05
8.39E+01	Th-232	3.42E-10	3.20E-10	8.65E-14	2.87E-10	3.40E-10	1.48	4.93E-11	7.85E+01	8.39E+01	3.10E+05
5.63E+04	Tl-208	1.76E-05	2.77E-06	1.81E-09	8.48E-06	1.40E-05	0.907	1.19E+05	8.86E+03	5.63E+04	8.61E+07
1.49E+09	Rn-220	1.71E-09	3.47E-10	2.22E-13	1.00E-09	1.54E-09	0.906	3.93E+05	3.02E+08	1.49E+09	2.33E+12

Check of BPRG External Equation

Radionuclide	Lambda	Ground Plane External Exposure Slope Factor (risk/yr per pCi/cm^2)	F_{SURF}	Hand Calc BPRG (pCi/cm^2)	Check Hand - BPRG difference (Rounding)
Ac-228	9.90E+02	8.56E-07	1.26	1.09E+03	3.98E+00
Bi-212	6.02E+03	1.71E-07	1.41	2.98E+04	5.76E+01
Pb-212	5.71E+02	1.26E-07	0.999	5.41E+03	6.51E+00
Po-216	1.46E+08	1.52E-11	0.88	1.30E+13	8.98E+09
Ra-224	6.91E+01	8.58E-09	0.983	9.76E+03	-5.41E+00
Th-228	3.62E-01	1.87E-09	1.37	1.68E+02	-5.89E-01
Th-232	4.93E-11	3.20E-10	1.48	8.39E+01	-1.51E-02
Tl-208	1.19E+05	2.77E-06	0.907	5.65E+04	1.52E+02
Rn-220	3.93E+05	3.47E-10	0.906	1.49E+09	-1.19E+05

MARSSIM equation 4-4 Combined PRG Calculation

Radionuclide	Ground Plane BPRG (pCi/cm^2)	Fraction of (COC) activity in chain	Fraction/PRG	1/(sum of fraction/PRG) Combined PRG
Ac-228	1.09E+03	0.119617	1.10E-04	
Bi-212	2.97E+04	0.119617	4.03E-06	
Pb-212	5.40E+03	0.119617	2.22E-05	
Po-216	1.30E+13	0.119617	9.20E-15	
Ra-224	9.77E+03	0.119617	1.22E-05	
Th-228	1.69E+02	0.119617	7.08E-04	
Th-232	8.39E+01	0.119617	1.43E-03	
Tl-208	5.63E+04	0.043062	7.65E-07	
Rn-220	1.49E+09	0.119617	8.03E-11	
		sum of Frac check		(pCi/cm2)
		1.000000		**4.38E+02**
		dpm/100cm2=		9.73E+04
		1x10-4 PRG		9.73E+06

Th-232+D
(pCi/cm2)
5.24E+01
1.16E+04
1.16E+06

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Ground Plane BPRG (pCi/cm^2)	Radionuclide	External Exposure Slope Factor (risk/yr per pCi/g)	Ground Plane External Exposure Slope Factor (risk/yr per pCi/cm^2)	External Exposure Slope Factor (1 cm) (risk/yr per pCi/g)	External Exposure Slope Factor (5 cm) (risk/yr per pCi/g)	External Exposure Slope Factor (15 cm) (risk/yr per pCi/g)	F_{SURF}	Lambda	Soil Volume BPRG (pCi/g)	Ground Plane BPRG (pCi/cm^2)	Soil Volume BPRG (1 cm) (pCi/g)
1.09E+03	Ac-228	4.53E-06	8.56E-07	5.48E-10	2.49E-06	3.92E-06	1.26	9.90E+02	2.07E+02	1.09E+03	1.71E+06
2.97E+04	Bi-212	8.88E-07	1.71E-07	1.06E-10	4.82E-07	7.64E-07	1.41	6.02E+03	5.73E+03	2.97E+04	4.80E+07
5.40E+03	Pb-212	5.09E-07	1.26E-07	7.95E-11	3.46E-07	4.89E-07	0.999	5.71E+02	1.34E+03	5.40E+03	8.56E+06
-	Po-212	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	7.17E+13	-	-	-
1.30E+13	Po-216	7.87E-11	1.52E-11	9.73E-15	4.40E-11	6.90E-11	0.88	1.46E+08	2.51E+12	1.30E+13	2.03E+16
9.77E+03	Ra-224	3.73E-08	8.58E-09	5.50E-12	2.46E-08	3.56E-08	0.983	6.91E+01	2.25E+03	9.77E+03	1.52E+07
6.46E+01	Ra-224+D	7.77E-06	1.30E-06	8.42E-10	3.90E-06	6.33E-06	0.981	6.91E+01	1.08E+01	6.46E+01	9.97E+04
-	Ra-228	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	1.21E-01	-	-	-
6.27E-02	Ra-228+D	1.23E-05	2.16E-06	1.39E-09	6.39E-06	1.03E-05	1.09	1.21E-01	1.10E-02	6.27E-02	9.74E+01
1.69E+02	Th-228	5.59E-09	1.87E-09	1.03E-12	4.17E-09	5.49E-09	1.37	3.62E-01	5.64E+01	1.69E+02	3.06E+05
8.39E+01	Th-232	3.42E-10	3.20E-10	8.65E-14	2.87E-10	3.40E-10	1.48	4.93E-11	7.85E+01	8.39E+01	3.10E+05
5.63E+04	Tl-208	1.76E-05	2.77E-06	1.81E-09	8.48E-06	1.40E-05	0.907	1.19E+05	8.86E+03	5.63E+04	8.61E+07
1.49E+09	Rn-220	1.71E-09	3.47E-10	2.22E-13	1.00E-09	1.54E-09	0.906	3.93E+05	3.02E+08	1.49E+09	2.33E+12

Check of BPRG External Equation

Radionuclide	Lambda	Ground Plane External Exposure Slope Factor (risk/yr per pCi/cm^2)	F_{SURF}	Hand Calc BPRG (pCi/cm^2)	Check Hand - BPRG difference
Th-232	4.93E-11	3.20E-10	1.48	8.39E+01	-1.51E-02
Ra-228+D	1.21E-01	2.16E-06	1.09	6.29E-02	2.21E-04
Th-228	3.62E-01	1.87E-09	1.37	1.68E+02	-5.89E-01
Ra-224+D	6.91E+01	1.30E-06	0.981	6.46E+01	-2.23E-02

MARSSIM equation 4-4 Combined PRG Calculation

Radionuclide	Ground Plane BPRG (pCi/cm^2)	Fraction of (COC) activity in chain	Fraction/PRG	1/(sum of fraction/PRG) Combined PRG
Th-232	8.39E+01	0.1196172	1.43E-03	
Ra-228+D	6.29E-02	0.1196172	1.90E+00	
Th-228	1.68E+02	0.1196172	7.10E-04	
Ra-224+D	6.46E+01	0.6411483	9.93E-03	
		sum of Frac check 1.000000		(pCi/cm2) **5.23E-01**

Ra-224+D External SF in BPRG is = to Th-228+D external SF from Heast

BPRG manual states to use Th-228+D but it is not a choice in BPRG

BPRG ground plane SF and Fsurf are different between Ra-224+D and Th-228

dpm/100cm2=	1.16E+02
1x10-4 PRG	1.16E+04

Should be noted that the theoritical ground plane SF for Th-232+D equals Ra-228+D GPSF

When Th232+D calc done in cell L39 result is basically same as Ra-228+D.

The Th-232+D PRG is very close to that from Ra-228+D.

Th232 (mod for D)	6.25E-02
dpm/100cm2=	1.39E+01
1x10-4 PRG	1.39E+03

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